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Abrupt onsets capture attention independent of top-down control settings

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Previous research using a spatial cuing paradigm in which a distractor cue preceded the target has shown that new objects presented with abrupt onsets only capture attention when observers are set to look for them (e.g., Folk, Remington, & Johnston, 1992). In the present study, we used the same spatial cuing paradigm as Folk et al. (1992) to demonstrate that even when observers have an attentional set for a color singleton or a specific color feature, an irrelevant new object presented with an abrupt onset interfered with search. We also show that the identity of the abrupt-onset distractor affects responses to the target, indicating that at some point spatial attention was allocated to the abrupt onset. We conclude that abrupt onsets or new objects override a top-down set for color. Abrupt onsets or new objects appear to capture attention independently of top-down control settings.

One of the most fundamental questions is whether we are able to control what we select for attention from our environment. Overt or covert selection may be controlled either by the properties of the stimulus field or by the intentions, goals, and beliefs of the observer (for recent reviews, see, e.g., Burnham, 2007; Rauschenberger, 2003; Ruz & Lupiáñez, 2002; Theeuwes & Godijn, 2001). When we intentionally select only those objects and events needed for current tasks, selection is said to occur in a voluntary, goal-directed manner. When, irrespective of our goals and beliefs, specific properties present in the visual field determine what we select, this selection is said to occur in an involuntary, stimulus-driven manner. These two mechanisms of selection have been referred to as *bottom-up* and *top-down* attentional control (see, e.g., Eriksen & Hoffman, 1972; Posner, 1980; Theeuwes, 1991b; Yantis & Jonides, 1984). When objects or events receive priority of processing, independent of the observer's goals and beliefs, this is *attentional capture* (see, e.g., Yantis, 1996). When such events trigger an exogenous saccade to the location of the object or event, this is *oculomotor capture* (Theeuwes, Kramer, Hahn, & Irwin, 1998).

Even though controversy continues over whether salient, static singletons capture attention in a purely bottom-up way (for recent discussions, see Leber & Egeth, 2006; Theeuwes, 2004; Theeuwes & Van der Burg, 2007), there appears to be less controversy about attentional capture by suddenly appearing new objects or abrupt onsets. The finding that abrupt onsets might capture attention dates back to the early research of Eriksen and Hoffman (1972) and Jonides (1981), which showed that participants' attention was automatically drawn to an exogenous cue. Subsequent research by Todd and Van Gelder (1979) showed that onset stimuli were detected faster than their no-onset counterparts in tasks requiring rapid eye movements as responses. As the task demands were made more complex, Todd and Van Gelder observed that the advantage for onset stimuli increased with the complexity of decisions that participants had to make. Yantis and Jonides (1984) demonstrated that peripheral cues captured attention because of their abrupt onsets. In the experiments, participants had to search for a specific target letter embedded in an array of two or four nontarget letters. While participants searched for the target letter, a new letter suddenly appeared in an empty location.

Following these demonstrations of the special status of onsets with regard to attentional capture, Theeuwes and colleagues (Theeuwes et al., 1998; Theeuwes, Kramer, Hahn, Irwin, & Zelinsky, 1999) showed that abrupt onsets also have the ability to capture the eyes. In this so-called *oculomotor capture paradigm*, participants were instructed to make a saccadic eye movement toward the only gray element in the display. On some trials, an irrelevant new object presented with an abrupt onset was added to the display. Participants knew that the onset was irrelevant and also knew that they had to ignore it. The condition in which

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a to-be-ignored onset was presented somewhere in the visual field was compared with a control condition in which no sudden onsets were added to the display. The results showed that when no new object was added to the display, observers made saccades that generally went directly to the uniquely colored circle. However, in those trials in which a new object was added to the display, in about 30%–40% of the trials the eye went in the direction of the abrupt onset. Moreover, in a subsequent eye movement study, Theeuwes, de Vries, and Godijn (2003) showed that under the very same circumstances, irrelevant salient *static* singletons (such as a uniquely colored element) only captured attention, not the eyes. Therefore, transient singletons seem to have a different effect than static singletons, confirming the special role of abrupt onsets.

All of these studies have demonstrated the special status of abrupt onsets in capturing attention. The reason for this special status may be that onsets are accompanied by luminance transients (see, e.g., Jonides & Yantis, 1988; Theeuwes, 1990, 1994, 1995; Yantis & Jonides, 1984) or that they represent new objects (e.g., Davoli, Suszko, & Abrams, 2007; Yantis & Hillstrom, 1994). Regardless of the underlying mechanism, it is generally agreed that onsets have the ability to capture attention in an exogenous manner.

Whether attentional capture by onsets is truly exogenous has been challenged by the *involuntary contingent-orienting* (or *contingent-capture*) hypothesis of Folk, Remington, and Johnston (1992). According to this hypothesis, whether or not an object captures attention is completely dependent on attentional control settings. Participants are able to compose a certain attentional set, which contains the dimensions or features of the target that the participant has to look for in a task (also called a *task set*). Only elements in the visual field that possess the properties that match the information in the attentional set will capture attention. This holds for static stimuli, as well as for dynamic events like onsets or motion. To provide evidence for this hypothesis, Folk et al. (1992) conducted an experiment in which participants were induced to adopt an attentional set for a certain stimulus property, such as an onset or a color. In the design, the presentation of a search display, which contained a stimulus dimension that participants had to look for, was preceded by a cue that gave an incorrect or correct (henceforth called *valid* or *invalid*) indication of the location where the target would appear. This cue could feature the same dimension as the target element or a different one. For example, a color search display could be preceded by either an onset cue or a color cue. The critical finding here was that only when the cue was for the same dimension as the target element was a considerable validity effect of the cue found. When the cue was not for the target dimension, it did not affect the response times (RTs) to the target, regardless of its validity.

The contingent-capture hypothesis of Folk et al. (1992) is consistent with notions put forward by Bacon and Egeth (1994) regarding a top-down set for specific search modes (i.e., feature search vs. singleton detection mode), and with notions suggested by Yantis and Egeth (1999) regarding a top-down attentional set for singletons. In this respect, the contingent-capture hypothesis may account for findings of attentional capture by *static* singletons (but for a different view, see Hickey, McDonald, & Theeuwes, 2006; Theeuwes, 1991a, 1992; Theeuwes, Atchley, & Kramer, 2000). However, the predictions of the involuntary contingent-orienting hypothesis regarding abrupt onsets seem to be inconsistent with earlier findings, which have shown that abrupt onsets are unique in their ability to capture attention without an attentional set (Jonides & Yantis, 1988; Yantis & Egeth, 1999).

The discussion of whether transient luminance or the appearance of a new object causes abrupt onsets to capture attention (see, e.g., Yantis & Hillstrom, 1994) has led to discussions regarding the original Folk et al. (1992) studies. The onset in Folk et al.'s (1992) experiments consisted of the appearance of a character inside a boundary box, instead of the presentation of an object at a previously empty location. This could be a violation of the requirement that the onset has to be a new perceptual object to capture attention. Instead of being regarded as the appearance of a new perceptual object, these onsets could be perceived as a property change of a previously present object (the boundary box), which by itself does not always capture attention (Jonides & Yantis, 1988). To address this issue, Folk and Remington (1999) conducted a series of new experiments using new perceptual objects in combination with their usual precuing paradigm. Consistent with the earlier findings, they found that onsets presented in empty locations (i.e., so-called *new* objects) only captured attention when participants were set for onsets but not for color. In line with their hypothesis, capture was fully contingent on the attentional control settings.

However, there is one important difference between the experimental paradigms favoring capture by abrupt onsets as well as by salient singletons (e.g., Theeuwes, 1992, 1994; Yantis & Jonides, 1984) and the precuing paradigm of Folk and colleagues (e.g., Folk et al., 1992) supporting the contingent-orienting hypothesis. In experiments using the first paradigm, the target and distracting element were presented simultaneously, exactly at the moment participants needed to start searching. However, in the classic precuing paradigm of Folk et al. (1992), the distracting element (the cue) preceded the search display by 150 msec. In other words, participants had to ignore a "cue" that preceded the search display. As argued by Theeuwes et al. (2000), it is possible that the delay between cue and search display was long enough to overcome attentional capture by the irrelevant cue (see also Theeuwes, 1994). In other words, disengagement of attention from the cue may have been relatively fast when the cue and target did not share the same defining properties (e.g., the cue was red and the target was an onset), whereas disengagement from the cue may have been relatively slow in cases in which the cue and target shared the same defining properties (e.g., both were red). Such a mechanism could explain the contrast between the RT costs when the cue and target have the same defining characteristics and the lack of costs when cue and target are different. In this view, the contingent-capture hypothesis can explain why disengaging attention from a particular location may be easier when an element presented at that location is not in line with the top-down control settings. However, this does not imply that capture of attention by an irrelevant cue singleton cannot occur; it simply indicates that after a certain time, participants are able to exert top-down control over the erroneous capture of attention by the irrelevant singleton.

In line with this explanation, Theeuwes et al. (2000) provided strong evidence for the claim that once attention is captured by an irrelevant singleton, it only takes a very brief time to disengage attention from that location. Theeuwes et al. (2000) used a visual search task similar to that of Theeuwes (1992), in which participants searched for a shape singleton (a single gray diamond among eight gray circles). Prior to the presentation of the target display, a color singleton was presented at different SOAs (50, 100, 150, 200, 250, and 300 msec). Theeuwes et al. (2000) showed that for conditions in which target and distractor were presented in close temporal proximity (<100 msec), the distractor interfered with search, suggesting that not enough time had passed to overcome attentional capture. However, when the singleton distractor was presented a considerable time before the presentation of the singleton target (i.e., with an SOA from 150 to 300 msec), the distractor no longer interfered with search, suggesting that participants were able to overcome capture by the irrelevant singleton.

The present research was intended to further explore the ability of abrupt onsets to capture attention while still using the classic precuing paradigm of Folk et al. (1992; Folk & Remington, 1999; Folk, Remington, & Wright, 1994). A search display was preceded by a cue display of the same dimension as the target. Participants were set for color, since they had to search for a color singleton throughout the whole experiment. In some trials, an abrupt onset (i.e., a new perceptual object) was presented at a random and empty location. However, unlike Folk and Remington (1999), we presented the abrupt onset not during the cue display but simultaneously with the search display, as is typically done in traditional visual search experiments investigating the role of irrelevant distractors (e.g., Christ & Abrams, 2006; Theeuwes, 1994, 1995; Yantis & Jonides, 1990). As noted, by presenting the target and the onset distractor simultaneously, the data will reveal any potential capture effect of the onset distractor because, unlike in the spatial cuing paradigms of Folk and Remington (1999; Folk et al., 1992), there is no time to recover from capture (see Theeuwes et al., 2000).

EXPERIMENT 1

The present experiment used the Folk et al. (1992) precuing paradigm. We created two experimental conditions. One was regarded as the "no-onset" condition and was the same as the color cue, color target condition of Folk et al. (1992). The participant's goal was to find a red character among white characters that appeared inside placeholder boxes at four possible locations in the visual field. Before the search display appeared, a precue that had the same color as the target was presented at any of the four potential target locations. Since the cue was a color singleton and participants were set for color, it was expected that the cue would capture attention and result in a significant difference in RTs depending on the validity of the cue, just as in Folk et al. (1992).

In the other, "onset" condition, a boundary box containing a white character appeared at a random empty location between two of the already present boundary boxes. This extra character could be regarded as an abrupt onset of a new perceptual object. The involuntary contingent-orienting hypothesis of Folk et al. (1992; see also Folk & Remington, 1999; Folk et al., 1994) predicts that when participants are set to search for color, the sudden appearance of an abrupt onset should have no effect on performance.

To ensure that differences in RTs could be attributed to attentional capture and not to "attentional misguidance," we ensured that the appearance of the new object met the criteria set by Yantis (1993) for stimulus-driven attentional capture—in other words, that the distracting element did not share a defining or reporting property (Duncan, 1985) with the target character. In this case, the *defining property* was the red color of the target character, which the onset did not share, since it was white. The *reporting property* in this task was character identity, so we made sure that the identity of the onset distractor never matched the identity of a target character. Since the onset character in the present task was always an "O" and the target character was either an "X" or an "=" character, the latter demand was met as well, since the distractor identity was not among the possible identities of the target the participants were to respond to.

Method

Participants. Fourteen first-year students from the School of Psychology at the University of Sydney participated in this experiment in exchange for course credit. The participants ranged in age from 18 to 25 years, and all reported normal or corrected-to-normal visual acuity and color vision.

Apparatus. The stimuli were presented on a 15-in. TFT screen with a Dell OptiPlex GX520, containing an Intel Pentium IV 3-GHz processor and 512 MB of internal memory. The experiment was created and run with E-Prime Version 1.1 (SP3). The slides consisted of BMP images with a resolution of 640 × 480 pixels.

Stimuli. There were three basic types of displays: a fixation display, a cue display, and a search display, all of which had a black background. The fixation display consisted of a pale white fixation cross at the center of the screen, surrounded by four light gray [RGB(167, 169, 172)] placeholder boxes with a width of 2.6º of visual angle, based on an approximate distance from the screen of 40 cm. The four boxes were positioned above, below, to the left, and to the right of the fixation cross, along a virtual circle with a radius of 20º of visual angle and the fixation cross at the center.

The cue display consisted of the same elements as the fixation display, with the addition of four dots, with a diameter of 1.4º of visual angle, positioned along the outside center of each side of all of the placeholder boxes. One set of these dots surrounding one of the placeholder boxes had a red color [RGB(236, 43, 39), luminance 62.2 cd/m^2] and indicated the cued location. All of the dots surrounding the other boxes had a bright white color [RGB(255, 255, 255)]. In the search display, an "X" (21-point Myriad Roman) or an "=" (22-point Myriad Roman bold) were placed in each of the boxes. There were always two "X"s and two "="s present.

Three of the characters inside the boxes were bright white, and the one designating the target character was red. The search display could contain all possible combinations of characters in the four boxes, of which one of the characters was always red.

In the onset condition, one extra character (an "O" with a bright white color and placed inside a light gray boundary box) appeared in the search display, located between two other boxes on the virtual circle on which all other boxes were placed. Examples of these display types, as well as their order of appearance, are presented in Figure 1.

Design. There were two within-subjects conditions. In the onset condition, an additional object (an abrupt onset) was added to the display. In the no-onset condition, everything was the same as in the onset condition, except that no new object was added to the display. In both conditions, the cue display could give a correct or an incorrect indication of the location where the target character might appear, but the location was correct at chance level. Thus, in 25% of the trials the red dots surrounded the box in which the target character would appear, which was considered a *valid* cue, and the other 75% of the trials were *invalid*, with the red dots surrounding a box other than the target.

In the onset condition, an extra distractor character was presented simultaneously with the search display. This character appeared inside a boundary box identical to the other four boxes already present on the display, but in a previously empty location. The extra onset character could appear between any two of the already-present placeholder boxes, and it appeared equally often in each of the four possible locations throughout the experiment.

The onset and no-onset conditions were presented in six mixed blocks of 80 trials each. A total of 50% of the trials in a block had no-onset search displays, and the other 50% consisted of onset search displays. These two types of search displays were randomly mixed within a block.

Procedure. Participants were tested in a 1-h session. Before the experiment started, oral instructions were given to familiarize the participants with the task to be performed. These instructions stressed that they should use different hands for pressing the two buttons on the keyboard and not move their eyes away from fixation during a trial, because this could impair their performance.

The experiment commenced with the presentation of general instruction slides that explained the main course of the experiment. Participants were told that the abrupt onset was irrelevant to the task and would never contain a target character. Finally, the slides also stressed that participants should react as fast as possible without making too many mistakes. After the general instruction slides, the participants began with a block of 40 practice trials. They were prompted to press the space bar when they were ready to begin with the real trials, after which they were presented with six blocks of 80 trials. At the end of each block, participants were advised to take a rest and were forced to wait for 30 sec before they could press a key to begin the next block of trials.

Trials began with the presentation of the fixation display for 500 msec. Then the fixation cross blinked off and on for 50 msec, to notify the participant of the start of a trial. The fixation display remained on-screen for a period randomly chosen from 1,000, 1,100, 1,200, 1,300, or 1,400 msec, in order to eliminate any effects of expectancy. After this foreperiod, a cue display was presented for 50 msec, after which the fixation display was shown again for 100 msec, which served as an interstimulus interval (ISI). After this interval, the search display was presented until the participant responded or, when no response was detected, for 2,000 msec. When no response was detected, the trial was counted as an error. Throughout a trial, the four placeholder boxes were constantly visible.

After a response was given, distinctive sounds were played for correct and for incorrect responses. If the response was incorrect, the experiment paused for 10 sec, showing a counter counting down from 10 to 0 sec, to let participants regain their focus. If a response was not made before 2,000 msec, the trial was registered as an error and the participant had to wait 10 sec before the trial procedure continued. Following the response of a participant, there was an intertrial interval of 500 msec before the fixation cross blinked again to indicate the start of the next trial.

Results

All RTs above 1,000 msec (which was approximately 4 *SD*s from the mean) were regarded as errors and removed from the data set, as were incorrect responses. This led to a loss of only 5.2% of the trials.

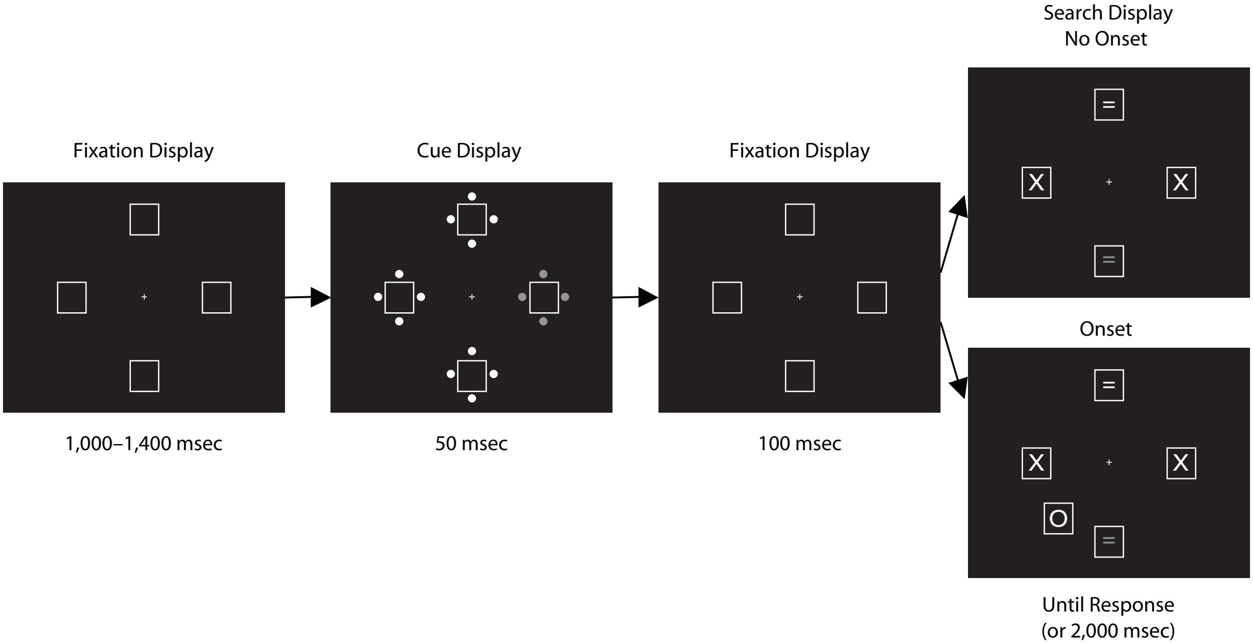

Figure 1. The sequence of events in a typical trial. In this figure, dark gray represents the color red, and white represents the color white; the placeholder boxes were always presented in gray. First, a fixation display was shown for 500 msec, after which the central fixation cross was turned off for 50 msec. Then the fixation display was shown again for a random period of 1,000, 1,100, 1,200, 1,300, or 1,400 msec. The cue display was presented for 50 msec. After an ISI of 100 msec, the search display was presented for 2,000 msec or until the participant responded. An example of an invalid trial is depicted, since the locations of the red dots in the cue display and of the red character in the search display differ.

Figure 2 shows the participants' mean RT and error percentages in the SOA and cue validity conditions. The individual mean RTs were submitted to a repeated measures ANOVA with onset presence (onset or no onset) and cue validity (valid or invalid) as factors.

There was a significant main effect of the presence of the sudden onset [$F(1,13) = 7.915, p < .05$], such that participants were slower in the response to the target when an onset was present (see Figure 2). In addition, cue validity was highly significant [$F(1,13) = 276.852, p < .001$], replicating the traditional Folk et al. (1992) effect demonstrating that a cue that shares the feature properties of the target captures spatial attention. Most importantly, there was no significant interaction between the validity of the cue and the presence of an onset [$F(1,13) = 1.329, p = .270$].

Error rates for the various conditions were well below 10%. Participants made significantly more errors in the invalid than in the valid cue condition [$F(1,13) = 15.443, p = .002$], indicating that an invalid cue made participants respond not only more slowly, but also less accurately. There were no differences in error rates between the onset and no-onset conditions [$F(1,13) = 0.240$].

Discussion

The present results replicate one of the main findings of Folk et al. (1992): When participants have an attentional set for a color, a "to-be-ignored" cue that has the same color as the target captures attention. Even though the cue was not informative about the location of the upcoming target singleton, participants were not able to ignore it. This is a replication of the classic finding of Folk et al. (1992) and signifies that attentional capture is (or at least can be) contingent on top-down settings that are established "offline," on the basis of current attentional goals. According to the contingent-capture model, only stimuli that match the top-down control settings will capture attention; stimuli that do not match the top-down settings should be ignored.

Even though it is clear that participants were set for a color singleton, the presence of an abrupt onset slowed responding. Indeed, regardless of whether the color cue was valid or invalid, in the onset condition, RTs were slowed by about 10 msec. One way to explain this slowing is that attention was captured by the abrupt onset, an interpretation that is consistent with findings from many previous studies in various paradigms that have shown the ability of onsets to capture spatial attention (see, e.g., Belopolsky, Theeuwes, & Kramer, 2005; Christ & Abrams, 2006; Donk & Theeuwes, 2001; Enns, Austen, Di Lollo, Rauschenberger, & Yantis, 2001; Gellatly, Cole, & Blurton, 1999; Remington, Johnston, & Yantis, 1992; Theeuwes, 1990, 1994; Yantis & Jonides, 1984). If the distraction effect caused by an abrupt onset is indeed due to attentional capture, one must then conclude that this finding is inconsistent with the contingent-capture hypothesis of Folk et al. (1992), because participants in this experiment were set for color, and therefore onsets should not have captured attention.

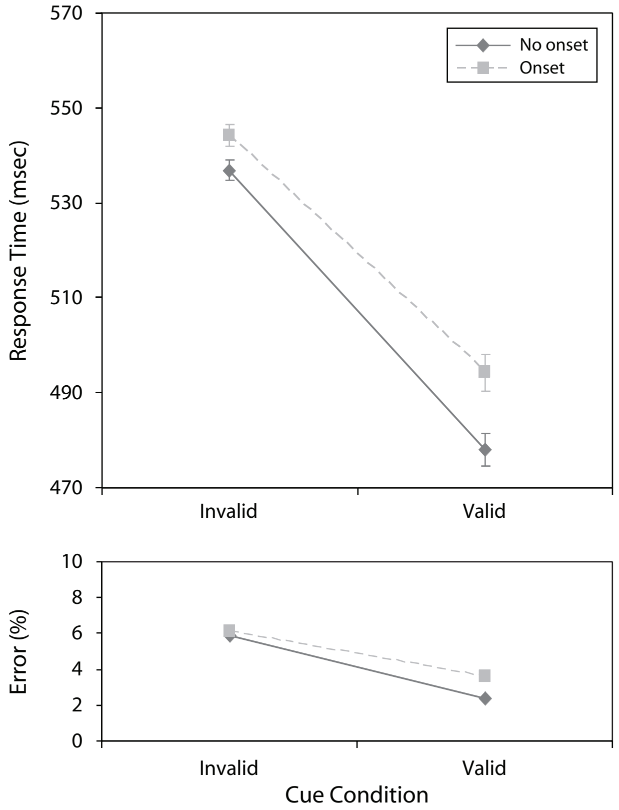

Figure 2. Experiment 1: Mean response times for validly and invalidly cued positions with and without the presence of an abrupt onset.

EXPERIMENT 2

The first experiment showed that even when the classic Folk et al. (1992) spatial cuing paradigm is used, there is an effect of the appearance of an onset distractor when presented at an empty location in the search display. This finding is consistent with other studies using different paradigms that have demonstrated the extent to which abrupt onsets can capture attention (e.g., Christ & Abrams, 2006; Remington et al., 1992; Theeuwes, 1994, 1995).

Even though Experiment 1 confirms the notion that onsets capture attention in a purely exogenous way, one could argue that even in that experiment the participants were set to look for onsets. Indeed, since the onset was presented simultaneously with the target elements (the "X"s and "="s) inside the placeholder boxes, it is possible that the abrupt onset captured attention because participants were set to look for it. For example, Gibson and Kelsey (1998) argued that the abrupt onset of a new object may capture attention because observers are prepared for the abrupt onset of the entire display (see also Burnham, 2007). Participants may adopt a *set for display-wide features* because the abrupt onset of the search display typically signals the presence of the target in a very general sense. In other words, it is feasible that, in addition to an attentional set for color, participants also adapted a default set for abrupt onsets because the abrupt onset of all of the elements inside the placeholder boxes signaled the presence of the target.

To address this concern, in Experiment 2 premasking elements were placed inside the placeholder boxes. These elements consisted of overlapping "X," "=," and "|" characters hiding the identities of the characters to appear. When the identities of the elements to search among needed to be revealed, the irrelevant line segments were removed, in analogy to figure-eight premasking characters used in Yantis and Jonides (1984).

Method

Participants. Thirteen first-year students from the University of Sydney participated in this experiment in exchange for course credit. The participants ranged in age from 18 to 24 years, and all reported normal or corrected-to-normal visual acuity and color vision. None of the participants had participated in the previous experiment of this study.

Apparatus and Stimuli. The apparatus and stimuli were similar to those in Experiment 1, with the exception of white premasking characters (62.2 cd/m^2), which were placed inside the boundary boxes. Figure 3 provides an example. When the search display was presented, the extra line segments hiding the characters on the search display were removed, making the characters to search among visible.

Design and Procedure. The design and procedure were identical to those of Experiment 1. Instead of appearing at an empty location inside a placeholder box, the target character was now revealed by changing the color of one of the premasking characters and, at the same time, removing the line segments that hid it.

Results

Erroneous responses were removed, as were responses above 1,000 msec, which led to a loss of 5.2% of the trials. Figure 4 shows the participants' mean RTs and error percentages in the SOA and cue validity conditions. As in Experiment 1, there was a main effect of onset presence [$F(1,12) = 28.410, p < .001$], indicating that the presence of an onset slowed search for the color singleton. Also, the main effect of cue was highly significant [$F(1,12) = 78.470, p < .001$]. Finally, as in Experiment 1, the interaction between cue validity and onset presence was not reliable [$F(1,12) = 0.170, p = .687$].

Error rates were well below 10%. Again, participants made significantly more errors in the invalid than in the valid cue condition [$F(1,12) = 21.429, p = .001$]. There were no differences in error rates for the onset and no-onset conditions [$F(1,12) = 0.302$].

Discussion

The present results are basically identical to those of Experiment 1. The presence of an onset distractor resulted in longer response latencies relative to the condition in which no onset was present. The results indicate that whether the search elements inside the placeholder boxes were presented by means of onsets (as in Experiment 1) or offsets (as in Experiment 2), this had no effect on the impact of the abrupt onsets. It appears that in the present experiments, in addition to an attentional set for color, participants did not adopt a general default set for onsets, as is advocated by the display-wide visual feature notion of Gibson and Kelsey (1998).

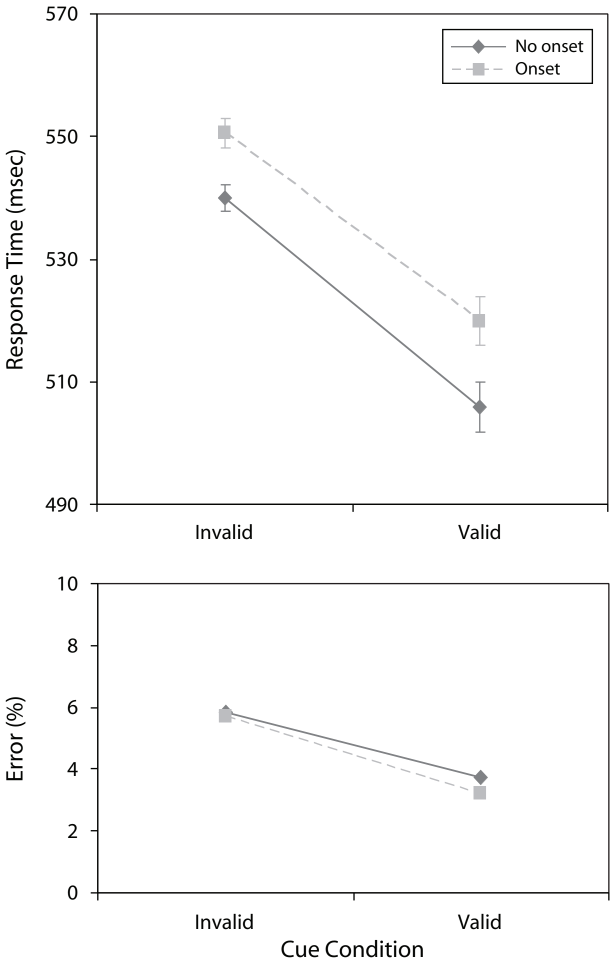

Figure 4. Experiment 2: Mean response times for validly and invalidly cued positions with and without the presence of an abrupt onset.

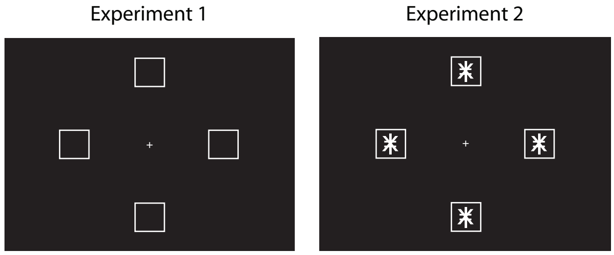

Figure 3. Examples of the fixation displays used in Experiments 1 and 2.

EXPERIMENT 3

Experiments 1 and 2 clearly show that the presence of an abrupt onset slows responding to a target. Even though participants were set for color, the onset nonetheless had an effect on their performance. Even though previous studies (e.g., Belopolsky et al., 2005; Christ & Abrams, 2006; Enns et al., 2001; Gellatly et al., 1999; Remington et al., 1992; Theeuwes, 1990, 1994; Yantis & Jonides, 1984) have suggested that onsets capture attention, one still could argue that the 15- to 25-msec cost caused by the onsets has nothing to do with attentional capture. Indeed, Folk and

Remington (1998) offered an alternative explanation for increases in RTs in conditions in which a distractor was present. They suggested that the increase in search time caused by the irrelevant singleton is due to what they call *filtering costs*, a notion first introduced by Kahneman, Treisman, and Burkell (1983). In the present experiments, the presence of the abrupt onset may have slowed the deployment of attention to the target item by requiring an effortful and time-consuming filtering operation. According to this line of reasoning, attention still goes directly to the uniquely colored item, but because the onset is present, directing attention to the uniquely colored item takes more time than it would if no onset were present. The filtering-cost explanation is compatible with the contingent-capture hypothesis because spatial attention only goes to the item (the uniquely colored item) that matches the attentional set for color; the hypothesis assumes that spatial attention does not go to the location of the abrupt onset.

To determine whether the performance costs due to the onset are the result of erroneous attentional capture or of filtering costs, we employed the so-called *identity intrusion technique*, first introduced by Theeuwes (1996) and Theeuwes and Burger (1998). Instead of presenting a neutral character "O" inside the abrupt onsets, in Experiment 3, the element inside the abrupt onset was either compatible or incompatible with the response to the target. The underlying notion is that if attention is allocated to the location of the abrupt-onset distractor, its identity will be processed (see, e.g., Kramer & Jacobson, 1991). Given this assumption, if attention is captured by the abrupt onset, a compatibility effect should be found, with longer RTs when the element inside the distractor is incompatible with the target than when it is compatible. If the abrupt onset does not capture attention, so that spatial attention is never allocated to the location of the onset, one would expect no compatibility effect whatsoever.

Method

Participants. Twenty-one first-year students from the School of Psychology at the University of Sydney participated in this experiment in exchange for course credit. The participants ranged in age from 18 to 25 years, and all reported normal or corrected-to-normal visual acuity and color vision. None of the participants had participated in either of the previous experiments.

Apparatus and Stimuli. The apparatus and stimuli were identical to those in Experiment 2, with the exception of the onsetting element. Instead of an "O" character inside the onset placeholder, an "X" or "=" appeared, with the same font and color properties as all of the other characters.

Design and Procedure. The design and procedure were basically the same as in the previous experiments, except that the compatibility of the element inside the onset distractor was manipulated. When an onset distractor was present, in half of the trials the item inside the onset distractor was compatible with the response to the target; in the other half, it was incompatible. Six blocks of 80 trials were presented.

Results

Erroneous trials and trials with responses above 1,000 msec were removed from the data, which resulted in a total loss of 6.7% of the trials. Figure 5 presents the results.

To investigate whether the presence of a distractor had an effect, the individual mean RTs were submitted to an ANOVA with distractor presence (onset vs. no onset) and cue validity (valid vs. invalid) as factors. The main effect of distractor presence was significant [$F(1,20) = 22.977$, $p < .001$], indicating that the presence of the onset slowed search. Again, the cue validity was significant [$F(1,20) = 75.774$, $p < .001$]. As in the previous experiments, there was no significant interaction between cue condition and presence of the onset distractor [$F(2,40) = 0.321$, $p = .649$].

Another ANOVA was performed on the individual mean RTs for the distractor conditions, with compatibility (compatible vs. incompatible) and cue condition (valid vs. invalid) as factors. The main effect of compatibility was significant [$F(1,20) = 5.222$, $p < .05$], indicating that the identity of the element inside the onset distractor affected the speed with which participants responded to the target. When the element inside the onset distractor was compatible, participants responded faster (M = 729 msec) than when it was incompatible (M = 759 msec). The interaction between cue validity and compatibility failed to reach significance [$F(1,20) = 0.929$, $p = .347$].

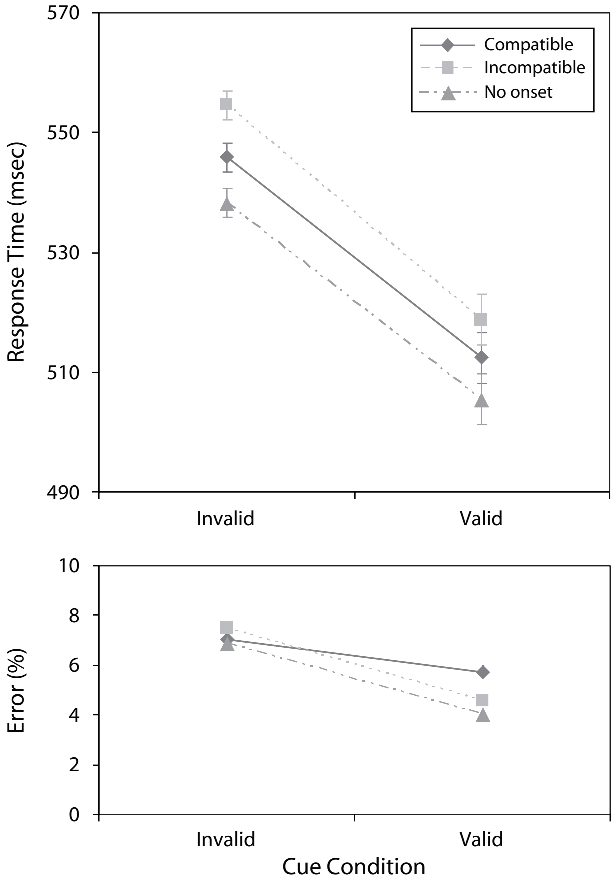

Figure 5. Experiment 3: Mean response times for validly and invalidly cued positions with and without an abrupt onset. In the compatible condition, the character inside the abrupt onset was compatible with the response to the target; in the incompatible condition, these two elements were incompatible.

All error rates were well below 10%. Again, error rates were higher in the invalid than in the valid condition [$F(1,20) = 15.977$, $p < .001$]. The presence of the onset had no significant effect on errors [$F(1,20) = 0.186$], nor did the compatibility of the onset distractor with the target [$F(1,20) = 1.463$].

Discussion

The present experiment shows a small but clear compatibility effect, suggesting that attention was allocated to the location of the onset distractor. The effect size of compatibility is comparable to that reported by Theeuwes (1996). On the basis of this finding, one has to conclude that even when participants are set to look for a color singleton, irrelevant abrupt onsets can capture attention. Note that the effect of the onset is not modulated by the validity of the cue, suggesting that even when attention is directed toward the location where the target item is going to appear, the onset may pull attention away toward the location of the onset. The observed compatibility effect indicates that the onset does not merely cause some type of nonspatial filtering cost but truly pulls attention to the onset location.

It is important to note that RTs in the incompatible and compatible conditions of this experiment are very similar to those observed in the onset condition of Experiment 2. Statistically, there is no difference between these conditions ($F < 1$), indicating that inserting a response-related character (an "X" or an "=") inside the onset element did not affect the extent to which the onset captured attention.

EXPERIMENT 4

The results of Experiments 1–3 show that when participants have a clear attentional set for color, an irrelevant abrupt onset nonetheless captures attention. Even though this clearly suggests that onsets capture attention independent of a top-down set for color, one still may rescue the contingent-capture hypothesis of Folk et al. (1992) by assuming that in our Experiments 1–3, participants engaged in what has been called *singleton detection* mode (see Bacon & Egeth, 1994; see also Lamy & Egeth, 2003). The idea is that participants can choose to search in a particular mode. When they engage the singleton detection mode, they choose to direct attention to the location having the largest feature contrast. In this mode, the most salient singleton will capture attention, whether it is the target or not. If, however, participants engage what is called a *feature detection* mode, they choose to direct their attention to a particular feature (e.g., the color red) rather than to any singleton. According to Bacon and Egeth, in this mode "goal-directed selection of a specific known featural identity may override stimulus-driven capture caused by salient featural singletons" (p. 493). Bacon and Egeth suggested that when observers "choose" the feature search mode, attentional capture by irrelevant singletons is eliminated. The notion that choosing a search strategy allows attentional control suggests that attentional capture is under top-down control (but see Theeuwes, 2004, who criticized the circularity of these search concepts).

If we apply this type of reasoning to the present experiments, it is possible that participants searched in singleton detection mode, allowing the onset singleton to capture attention. Because participants were always looking for a singleton (the only red element among white elements), it is possible that the other singleton (i.e., the onset) captured attention. To test whether the onset captured attention even when participants were engaged in a feature search mode, we changed the display so that they could no longer search for a singleton. Instead of a red target among white nontarget elements, participants had to search for one particular color (e.g., red) among elements that each had a different color (e.g., green, yellow, and blue). In this way, participants would be forced to use the feature search mode. The question was whether the onset would capture attention, even in this setup.

Method

Participants. Eight students from the Vrije Universiteit Amsterdam were paid for participation. They ranged in age from 18 to 24 years, and all reported normal or corrected-to-normal visual acuity and color vision.

Apparatus and Stimuli. The apparatus and stimuli were similar to those in Experiment 2, with the exception that the nontarget characters were colored instead of white. The colors red, green, yellow, and blue (all matched for luminance at 29 cd/m^2) were randomly assigned to each of the four characters. The abrupt onset was constrained to have the color of one of the nontarget elements.

Design and Procedure. Participants were instructed to look for one particular color throughout the whole experiment. The participants were balanced across the four different colors, such that 2 participants consistently searched for red, 2 for green, 2 for yellow, and 2 for blue. The color of the cue in the cue display matched the color a particular participant was looking for.

Results

Erroneous trials and trials with responses above 1,000 msec were removed from the data set, resulting in a loss of 8% of the total trials. Figure 6 displays the participants' mean RTs and error percentages in the onset presence and cue validity conditions. There was a main effect of onset presence [$F(1,7) = 6.575$, $p = .037$], indicating that the presence of an onset slowed search for the color singleton. Also, the main effect of cue was significant [$F(1,7) = 11.731$, $p = .011$]. The interaction between cue validity and onset presence was not reliable [$F(1,7) = 2.121$, $p = .189$].

Error rates were well below 10%. Participants made significantly more errors in the invalid than in the valid cue condition [$F(1,7) = 7.881$, $p = .026$]. There were no differences in error rates for the onset and no-onset conditions [$F(1,7) = 0.127$, $p = .732$].

Discussion

The present results are basically identical to those of the previous three experiments. Even when participants were forced to search for a particular color feature, the irrelevant abrupt onset captured attention. The present findings suggest that, regardless of whether participants are set to search for a unique color singleton (singleton detection mode, as in our Experiment 2) or a specific color feature (feature search mode, as in our Experiment 4), an abrupt onset captures attention and interferes with search.

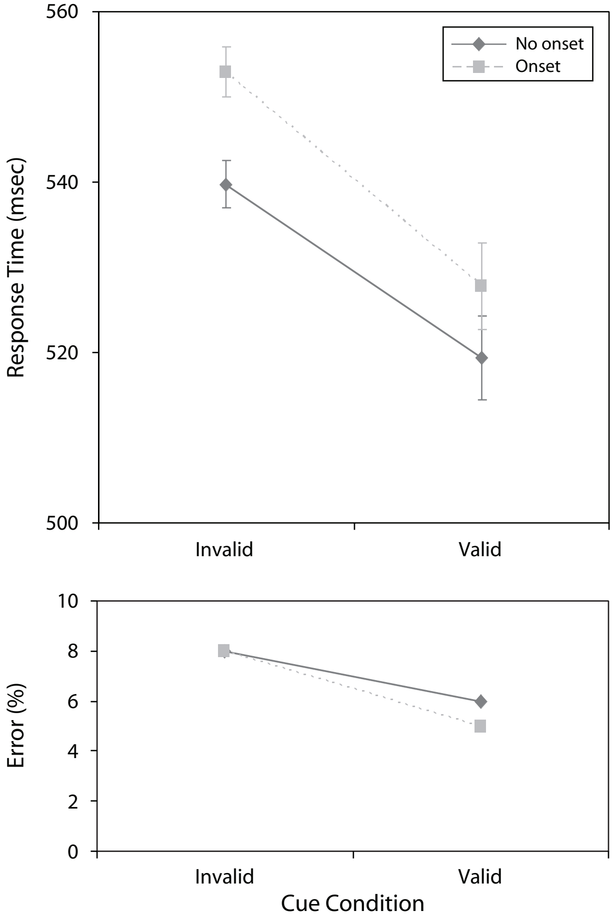

Figure 6. Experiment 4: Mean response times for validly and invalidly cued positions with and without the presence of an abrupt onset, in a task in which participants searched for a particular color feature.

GENERAL DISCUSSION

The present results are clear. In conditions in which participants have a clear attentional set for color, regardless of whether they are looking for a singleton or for a specific color, they cannot prevent attentional capture by an irrelevant abrupt onset. The results are consistent with the contingent-capture hypothesis in showing that an attentional set for color results in strong capture by a color cue. However, according to the contingent-capture hypothesis of Folk et al. (1992; Folk & Remington, 1999; Folk et al., 1994), an attentional set for color should have prevented attentional capture by abrupt onsets, because the hypothesis assumes that capture is fully dependent on attentional control settings.

The pattern of results obtained in the present study indicates that the effect of the attentional set on capture is very strong, generating cuing effects of about 40 msec. The distracting effect of the onset is relatively small (about 8–10 msec) and appears to be additive with cuing effects. This pattern of results implies that the distracting effect of the onset rides on top of the contingent-capture effect of the color cue, suggesting that independent of whether attention is allocated to a valid or invalid cue, the onset captures spatial attention for a very brief time before a response to the target can be emitted.

The present findings are inconsistent with those of Folk and Remington (1999), who conducted a study very similar to the present one. In their study, they also had conditions in which participants were set for a unique color, and they showed that a new object presented with an abrupt onset had no effect when the participants were set for color. Indeed, the conclusion of their study was that the appearance of a new object could not override a top-down set of color. Even though, on the face of it, these studies are very similar, there is one important difference between the present study and that of Folk and Remington (1999). In the present study, the irrelevant onset was presented simultaneously with the search display, whereas in Folk and Remington (1999) the onset was presented during the cue display; that is, the onsetting new object was presented before the presentation of the search display. In Folk and Remington's (1999) Experiments 1 and 2, the SOA between the cue and search displays was 150 msec, an SOA identical to those used in the original Folk et al. (1992) study. As argued, recovery from attentional capture can be relatively fast (see Theeuwes et al., 2000). Therefore, it is possible that in Folk and Remington's (1999) experiments, participants had their attention captured by the abrupt onset but were able to quickly disengage attention when they realized that the new object was not a uniquely colored item. Data show that a 150-msec SOA between cue and search display certainly provides enough time to recover from capture (see, e.g., Kim & Cave, 1999; Theeuwes et al., 2000). To address this issue, in Folk and Remington's (1999) Experiment 3, the SOA was reduced to 50 msec. The reasoning was that if the abrupt onsets capture attention, this should become visible when the search and cue displays are presented relatively close in time (i.e., within 50 msec). Even though this manipulation did not change the overall pattern of results, Folk and Remington (1999) indicated that there was a small distracting effect of the onset when the participants were set for color. Indeed, Figure 4 of Folk and Remington (1999) seems to suggest that the onset caused a distraction effect of about 8 msec. As noted by Folk and Remington (1999), this effect could very well indicate the "tail effect" of the recovery from capture. In our experiments, the SOA was basically zero, because the onset and the search display were presented simultaneously. Obviously, in those conditions, the distracting effect of the onset (an effect size of 10–20 msec) does become reliable, as we demonstrated in all four experiments.

Folk and Remington (1999) also employed the identity intrusion technique (used in our Experiment 3) to show in another way that the onset did not capture attention. In their Experiment 4, they placed a character inside the abrupt onset that was either compatible or incompatible with the response to the target. The abrupt onset with the character was presented for 50 msec during the cue display and was immediately masked for 50 msec; the cue display was replaced by the fixation display, followed by the search display after another 50 msec. In the critical condition, in which participants were set for color, Folk and Remington (1999) did not find a compatibility effect, suggesting that the onset did not capture spatial attention. Note that we used the very same technique in our Experiment 3 and did find a small yet reliable compatibility effect. It is not immediately clear why we found a compatibility effect and Folk and Remington (1999) did not, but it is feasible that when the onset is not relevant, a very brief presentation (i.e., 50 msec) of the interfering character inside the onset followed by a mask, as was employed by Folk and Remington (1999), may not be long enough to allow enough processing to cause a compatibility effect.

Alternatively, Folk and Remington (1998) argued that compatibility effects reported in previous studies (Theeuwes, 1996; Theeuwes & Burger, 1998) may not reflect the allocation of spatial attention but may instead be the results of parallel processing of target and distractor information. Even though this is a possibility, such a paradigm would still imply that at some point, either in serial or in parallel, attentional resources were allocated to the location of the abrupt onset. Indeed, it seems unlikely that Folk and Remington's (1999) criticism of the identity intrusion technique implies that identity information at the location of the distractor is processed without attention. Moreover, Folk and Remington (1999) used this very same identity intrusion technique to argue that the absence of a compatibility effect indicated that spatial attention did not go to the abrupt onset or new object.

Even though the present study shows that abrupt onsets capture attention even when participants have a top-down set for color, this does not imply that onset capture is never under top-down control. For example, Theeuwes (1991b) showed that when the upcoming target position was cued in advance by a 100% valid cue, an abrupt onset presented elsewhere in the visual field ceased to capture attention (see also Juola, Koshino, & Warner, 1995; Yantis & Jonides, 1990). In addition, Martin-Emerson and Kramer (1997) showed that the capture effect of the abrupt onset is reduced with an increasing number of no-onset elements in the display (see also Miller, 1989; von Mühlenen, Rempel, & Enns, 2005). In addition, Boot, Brockmole, and Simons (2005) showed that capture by onsets is eliminated when participants have to execute a concurrent auditory task, suggesting that onset capture may be dependent on the resources available.

The present study shows that onsets capture attention regardless of whether participants are looking for a color singleton (i.e., the singleton detection mode) or for a specific color (i.e., the feature search mode). Irrespective of these search modes, and consistent with the contingent-capture hypothesis, the matching color cue captured attention, resulting in a large spatial cuing effect. At the same time, regardless of the top-down search mode, the irrelevant onset also captured attention. The discovery that the search mode had no significant effect in our study adds to the growing number of studies supporting the notion that these search modes may not be a very useful distinction (see Lamy & Egeth, 2003; Theeuwes, 2004; Theeuwes & Van der Burg, in press).

In conclusion, the present study demonstrates that even when participants have a clear attentional set for color, an irrelevant abrupt onset or new object captures attention. In other words, the appearance of the new object overrides a top-down set for color, regardless of whether participants are engaged in a feature search or singleton detection mode. Since the abrupt onset or new object in our experiments was always irrelevant for the task and was presented at an empty location that never contained a target, we argue that this attentional capture is genuinely exogenous.

AUTHOR NOTE

This work was based on the master's thesis of D.S. We thank Jim Brockmole, Angus Gellatly, and Michael Proulx for excellent comments on an early version of the manuscript. Correspondence concerning this article should be addressed to J. Theeuwes, Dept. of Cognitive Psychology, Vrije Universiteit Amsterdam, van der Boechorststraat 1, 1081 BT Amsterdam, The Netherlands (e-mail: j.theeuwes@psy.vu.nl).

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